STUDY OF SESAME OIL AS OIL BASED FLUID IN DRILLING OPERATION

by

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CERTIFICATION OF APPROVAL

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ABSTRACT

Drilling fluid is a critical component in the drilling process, where it facilitates to efficiently lift cuttings, maintain stable wellbore and produce sufficient hydrostatic pressure that could prevent the influx of formation fluids into the wellbore. . If the mud properties (physical, chemical, rheology properties and elastomeric effect) are incorrect, safety and economics of the drilling operations may be severely compromised. The usage of diesel oil as the continuous phase of drilling fluid is harmful to the environment especially marine environment in offshore drilling operation. Therefore, various bio-diesel oils had been introduced to replace the diesel oil.

Types of drilling fluid used in this project are oil based mud and synthetic based mud. The biodiesel oils (sesame oil) are used as oil phase in oil based mud and mineral oil (saraline) is used as synthetic fluid in synthetic based mud. This project is mainly to identify whether Sesame oil can be used as an alternative for bare oil to replace the diesel oil in oil based mud by examining the rheological properties and elastomeric effect of the muds. Most studies such as yield point measurement, plastic viscosity measurement, electrical stability and filtration loss measurement are conducted in Mud Laboratory in Block 15.

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I would like to take this opportunity to thank all parties involved in the completion of my final year project.It a chance for me to learn to be independent of doing a project and to improve myself more for the betterment of my future.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The use of oil based mud (OBM) has increased significantly in drilling operation. OBM is known to provide excellent shale inhibition, borehole stability, lubricity, thermal stability, corrosion inhibition, tolerance of contamination and ease of maintenance. Diesel oil had been widely used as the base oil since the introduction of OBM as drilling fluid. In early 1980's, there were many researches done on diesel oil as the base oil for drilling fluid. From these researches output showed that diesel oil is not suitable to be used as base oil due to high toxicity and aromatic contents exposure to the people and environment.

Therefore, vegetable oil based drilling fluids and synthetic based muds were introduced as environmental friendly alternatives. Normally, vegetable oil based drilling fluid is actually vegetable oil which already been converted to biodiesel and is used as continuous oil phase in OBM. However, in this study we will use Straight Vegetable Oil (SWO) as the oil phase by blending it with Linear Alkyl Benzene(LAB). The vegetable oil that is used in this project is the sesame oil. This oil have comparable physical and chemical properties with those of diesel oil that can be surely replaced the diesel oil in OBM. These vegetable oils are harmless to the environment since it has low aromatic content and less toxic.

The synthetic based mud (SBM) is also harmless to the environment and less toxic. It provides environmental superiority, technical acceptability and human health advantages. SBM is same with OBM. The oil phase is replaced with synthetic fluid which is mineral oil (Saraline). Oil based drilling fluid has synthetic oil as its base fluid. In this project, the properties of Sesame oil is to be measured and characterized as a substitute base oil. The compatibility of sesame oil with the drilling tools will also be determined through experiments.

1.2 Problems Statement

Diesel oil has been widely used in drilling operation but it is harmful to the environment and to people. The usage of vegetable oil and mineral oil can be an alternative based drilling fluid. Therefore, Sesame Oil might be a candidate solution as an alternative energy resource and it is comparable with diesel oil. Sesame oil is a potential bio-diesel oil to replace the oil phase in oil based mud because of:

- Developed locally
- Environmental friendly
- High viscosity
- High density

In order to develop a reliable, environmentally friendly, economical alternative to mineral oil, the chemical properties of Sesame Oil and also its compatibility as oil based mud with the drilling tools will be tested by conducting elastomer test. Besides that, physical properties of Sesame oil will also be determined through various laboratory tests.

1.3 Objectives

The objectives of this study are:

- To experimentally study and compare the rheology properties of the sesame oil and saraline oil as based oil in drilling operation.

- To identify the potential of sesame oil as alternative base fluid for oil based mud

- To measure the compatibility of Sesame Oil based drilling fluid in O-ring, blowout preventers (BOPs), pulsation dampeners, downhole mud motors and drilling bits by conducting elastomer test.

1.4 Scope of Study

The research will involve in the understanding of oil based mud. The study of this project can be broken down to the identification of the most suitable base oil to be used for drilling fluid by evaluating the rheology and elastomeric effect of the formulated mud. The key project activities involved:

- The reduction of sesame oil viscosity by blending it with Methyl Benzene (Toluene)

- Laboratory experiments to evaluate the efficiency of sesame oil and saraline oil used as base fluid in drilling operation.

1.5 Relevancy and Feasibility of Study

At the end of this study , a quantitative correlation of the rheology study of Sesame Oil and Saraline Oil will be produced. This correlation will give an idea in choosing the suitable drilling mud to be used in drilling operation. The study focuses on experimental work particularly rheology test in the lab, using the three base fluids with particular attention given to the characteristics of Sesame oil and its compatibility with the drilling tools and logging tools. A limited amount of formulations is prepared within the time frame. Results collected are analyzed .

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Sesame Oil

Sesame oil, which is extracted from the sesame seeds plant, is a new alternative for vegetable-oil based mud that is potential to be developed locally, environmentally friendly, and able to meet the standard requirement of OBM. It has density and viscosity higher than any other vegetable oils. Sesame oil has SG of 0.923 (diesel oil has SG of 0.84 in 60° F (API, 1998) and viscosity of 23 centistokes in.

Sesame oil can possess different physical and chemical properties. However, regardless of its country of origin or season in which it was grown, its chemical composition remains relatively constant. Like other vegetable oils, Sesame oil is a triacylglycerol composed of various fatty acids and glycerol. The fatty acids consist of up to 85% ricinoleic acid and varying small amounts of saturated and unsaturated fatty acids. The high content of ricinoleic acid is the reason for the high value of sesame oil and its versatile application possibilities in the chemical industry.

Fatty Acid	Nomenculature	Percentage
Palmitic	C16:0	7-12
Palmitoleic	C16:1	Trace-0.5
Stearic	C18:0	3.5-6.0
Oleic	C18:0	35-50
Linoleic	C18:2	35-50
Eicosenoic	C20:1	Trace-1.0

Table 1 : Sesame oil Composition

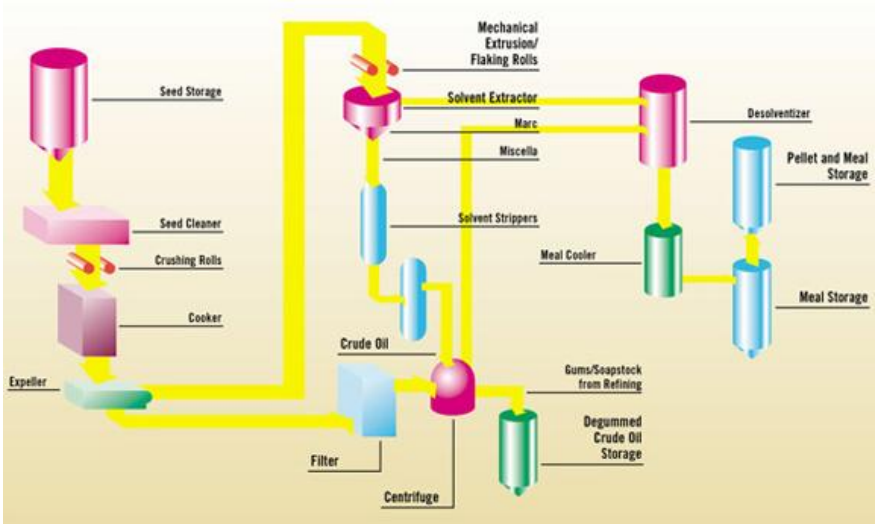

Figure 1 : Typical procedure for extraction and preparation of sesame oil for further modification

TEST	METHOD	RANGE
Specific gravity @ 25°C	USP	0.916-0.921
Iodine value	USP	103 - 116
Saponification value	USP	188 - 195
Free fatty acids	USP	< 2.0 mL of 0.02 N NaOH
Cottonseed oil	USP	absent
Identification	USP	passes
Unsaponifiable matter	USP	< 1.5%
Solidification range of fatty acids	USP	20° - 25 °
Heavy metals, Method II	USP	<0.001% max

Color Gardner	AOCS Td la-64
Appearance	Greenish yellow, bright & clear oily liquid
Flavor and Odor	Almost odorless

Table 2: Physical and chemical properties of Sesame Oil

2.2 Saraline Oil

Saraline 185V is a quality drilling fluid sourced from clean natural gas, it contains no aromatics and contaminants such as sulphur and amines. Saraline 185V is classified as a synthetic base drilling fluid because it is derived from the reaction of a purified feedstock as opposed to highly refined mineral oils which is the result of distillation as well as refining of crude oil. Saraline 185V readily biodegrades, is non-toxic in the water column and has low sediment toxicity. It has a low viscosity, a low pour point and relatively high flash point making it ideal for deepwater exploration. It is widely used as a non-aqueous base fluid in an invert emulsion drilling mud.

2.3 Biodiesel

Biodiesel is define as diesel- equivalent, processed fuel consequent from biological sources. Biodiesel is the name for variety of ester-based oxygenated fuels from renewable biological sources. It can be made from processed organic oils and fats. Chemically define biodiesel is as monoalkyl esters of long chain fatty acids derived from renewable biolipids. Normally it is produced throughout the reaction of vegetable oil or animal fat with alcohol like methanol or ethanol with the help of certain catalyst to come out with methyl ester and glycerine.

2.4 Base Fluid Properties

There are certain requirements to be identified whether the oil can be used as base fluid in drilling mud. The requirements aspects are as follows;

2.4.1 Kinematic Viscosity

It should be as low as possible. This allows the oil based mud to be formulated at lower oil/water ratio and gives better rheology (lower plastic viscosity) especially at lower mud temperature.

2.4.2 Flash Point

It should be greater than 100°F. Higher flash point will minimize fire hazards as less hydrocarbonvapours is expected to generate above the mud.

2.4.3 Pour Point

It should be lower than the ambient temperature to allow pumpability of mud from storage tanks.

2.4.4 Non-toxic and low aromatic content

Base oil should have total aromatic hydrocarbon content of less than 5%. It should be non-acutely toxic in a standard 96 hr LC 50 toxicity test, performed using 100% water soluble fraction of the base.

2.5 Rheological Study

Rheology of fluids in the well is the relationship between the flow rate and the pressure required to maintain the flow rate (either in pipe or annulus). The relationships between these properties will affect circulating pressures, surge and swab pressures and hole cleaning ability. In this project, the rheological study comprises of plastic viscosity, yield point, electric stability and gel strength. Each study is so significant to choose a better base fluid.

2.5.1 Plastic Viscosity

Plastic viscosity relates to the resistance to flow due to interparticle friction. The friction is affected by the amount of solids in the mud, the size and shape of those solids and the viscosity of the continuous liquid phase.

Plastic Viscosity, PV= [600rpm Reading] – [300 rpm Reading]

Unit: **centipoise,cp**

2.5.2 Yield Point

Yield point estimates the portion of the total viscosity that comes from attractive forces between particles suspended in the mud.

2.5.3 Electric Stability

The electric stability (ES) of an oil-based drilling fluid mud is a property related to its emulsion stability and oil-wetting capability. ES is determined by applying a voltage ramped sinusoidal electrical signal across a pair of parallel flat-plate electrodes immersed in the mud. The resulting current remains low until a threshold voltage is reached, whereupon the current rises very rapidly. This threshold voltage is referred to as the ES of the mud and is defined as the voltage. Specification value: > 600volts

2.5.4 Gel Strength

Gel strength are determined in two-speed direct-indicating viscometer by slowly turning the driving wheel on top of the instrument by hand and observing the maximum deflection before the gel breaks. Gel strength may be measured after

allowing the mud to stand quiescent for any time interval of interest, but they routinely measured after 10 seconds (initial gel strength) and 10 minutes

Specification value;

Gel 10sec: **10 – 20 lb/100ft^2**

Gel 10min: **20 – 40 lb/100ft^2**

2.5.5 ***Viscosity***

Viscosity of fluids defined as the resistance of fluids to flow. Viscosity measured in the unit of poise which is equivalent to dyne-sec/cm2. One poise represents a high viscosity, therefore the generally unit that represents the fluids is centipoises. A centipoise is equivalent to 1/100 poise or 1 millipascal-second. This property of fluids is significant in hole cleaning to control the settling rate of drill cuttings generated by the drill bit through moving fluid and bring them up to the surface.

There are two main apparatus that the author has utilized in the laboratory which are marsh funnel and direct indicating viscometer. Marsh funnel is a simple device for routine measurement of drilling fluids viscosity. The viscosity measured through this apparatus is known as funnel viscosity. The Marsh funnel is dimensioned so that the outflow time of one quart freshwater (946 cm3) at a temperature of 70° ± 5°F (21° ± 3°C) is 26 ± 0.5 seconds. Thus, fluid which records a time more than 26 ± 0.5 seconds using the marsh funnel is more viscous compared to freshwater and vice versa.

2.5.6 ***Filtration***

Filtration control is one of the main factors considered essential in drilling. Filtration measures the relative amount of fluid lost through permeable formations or membranes when subjected to pressure. Thus, it is important to minimize the filtrate invasion to the formations. When drilling permeable formations, filtration rate is often the most important property where the hydrostatic pressure exceeds the formation pressure. Proper control of filtration improves the borehole stability chemically. This is because controlling the fluid loss minimizes the potentially detrimental interaction between the filtrate and the formation. Filtrate invasion may be controlled by the type and quantity of colloidal material and by filtration control materials.

2.6 Elastomers

Oil based drilling fluids can chemically alter the properties of elastomers used in drilling equipment, severely affecting life and function. The products affected include O-ring, blowout preventers (BOPs), pulsation dampeners, downhole mud motors and drilling bits. This study centers on the effects of selected environmentally safe sesame oil based mud on elastomers and logging tools.

The performance of elastomers in Sesame oil drilling fluid is strongly dependent upon fluid chemistry, operating temperature and the type of elastomer chosen for service. Caution and testing have to be done when selecting environmentally safe drilling fluids and compatible elastomers.

2.7 Density Measurement

Based oil samples expand as increase in temperature under condition of isobaric, while decrease in thermal expansion with increase of pressure under isothermal condition (R.Azrai,2010). Blended vegetable oil with mineral oil is proved to me more tolerance at High Pressure High Temperature scenario and it could be good and suitable candidate for drilling mud. On the other hand, mineral based oil is more compressible compared to blended vegetable oil. In addition, blended vegetable oil is more renewable and sustainable resource.

2.8 Biodiesel Based Drilling Fluids

Biodiesel is synthesized by interesterification. Oil crops, wild-bearing crops, engineering micro algae, vegetable oil, fats and hogwash oil can be used as the raw materials of interesterification. Biodiesel is renewable and can replace mineral diesel. The main component is fatty acid methyl ester (FAME). The characteristics of biodiesel are maximum of moisture content is 30%-45%, water can reduce oil viscosity and improve stability (Wu Mioa-Xin,2011), relative density is 0.8724-0.8886(Dong Fang,2012), good lubrication performance, it has excellent environmental friendly, low sulphur content, low sulfur oxide and sulfides, emission, biodegradation is high to 98% which is twice the mineral diesel, it can reduce accidental leakage pollution(SunPing,2002), good safety performance, high flash point, good in health, safety and environment issue.

2.8.1 Rheological Behavior of Biodiesel Based Drilling Fluid

Rheological behavior of biodiesel was considered at room temperature and high temperature compared to white oil. Apparent viscosity (AV), plastic viscosity (PV), and yield point (YP) of white oil, biodiesel oil, aged oil and aged biodiesel are being observed. The viscosity of biodiesel is lower than white oil, which is advantageous to the preparation of high density drilling fluid. The deviation of the

viscosity of biodiesel before and after aging is smaller than white oil, which indicates good stability of biodiesel at high temperature, so biodiesel can be used as base oil of drilling fluids for drilling operation at high temperature reservoir and formation.

Biodiesel not only exceeds the performances of normal oil-based drilling liquids but shows excellent environmentally compatibility as well. It is said to be environmentally friendly because it contain low sulfur content, without aromatic alkene, easily biodegradable. Besides, biodiesel has good safety performance like high flash point and not hazardous. On the other hand, biodiesel is renewable which is in line with the strategy of sustainable development(ChenXiu,2010).

2.9 Environmentally Safety Indication of Drilling Fluid

Acute toxicity tests (96-h, LC_{50}) is of the measuring test to evaluate the toxicity of diesel based fluids using *Mysidopsis bahia*(Sunde,E,1991). The results have shown that LC_{50} values close to 2,000 ppm are toxic according to US Environmental Protection Agency mud and cutting discharge regulation (EPA) (John Reis,1996). In contrast, drilling fluids formulated with mineral oil showed LC_{50} of 1,000,000 ppm, which is considered as non- toxic under the EPA criteria. The difference is due to the high toxicity of the aromatic hydrocarbons present in diesel.

2.9.1 Toxicity Test

LC50 value is the concentration of toxicant that kills 50% of the tested organism in a given exposure time. The suspended particulate phase, SPP, was obtained from the drilling fluids and used for toxicity test on marine shrimp and estuarine fish, both are marine organisms. High LC50 values correspond to low toxicity levels and viceversa. Drilling cuttings were also tested following the same procedure of LC50 in order to compare their toxicity levels before and after the application of the bioremediation method.

2.9.2 Biodegradation Tests

Aerobic biodegradability test was prepared according to OEDC protocols by testing the biochemical oxygen demand (BOD) for poorly soluble substances (OEDC Guidelines,1992).The closed bottle test measures the BOD and express biodegradation as a percentage of the chemical oxygen demand of the substance (COD). Glucose used as reference compound. Dissolved oxygen was measured in triplicate bottles once per week. It is considered that an organic compound is readily biodegradable when the biodegradation reaches 60% within 10 days after achieving an initial 10% of biodegradation, but it must end before day 28 of the testing period.

CHAPTER 3

METHODOLOGY

3.1 Methodology Flowchart

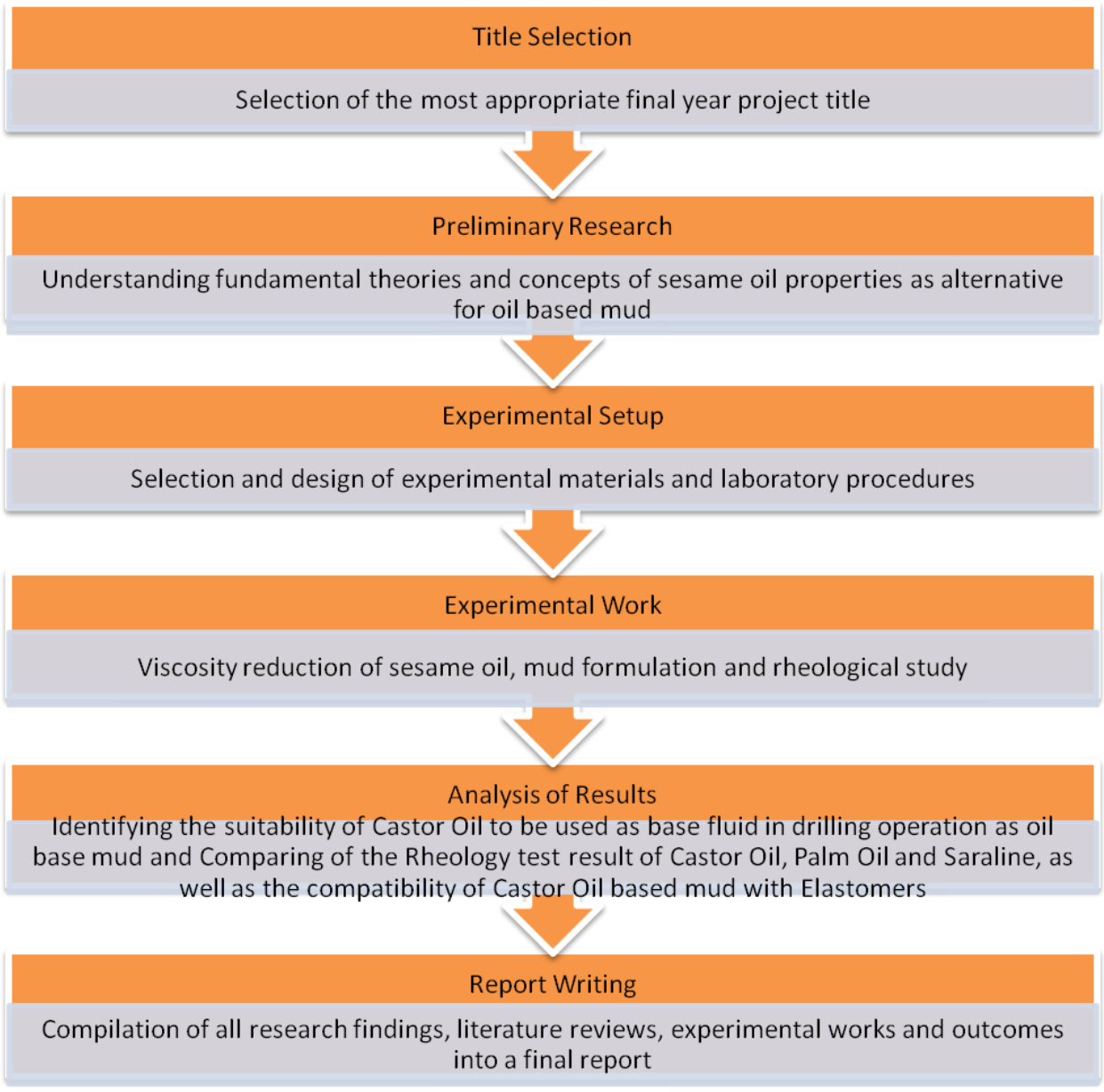

Figure 2: Methodology Flowchart

3.2 Addition of Methyl-benzene (Toluene) to Sesame oil as simple viscosity reduction process

The most common methods used to reduce oil viscosity in the Biodiesel industry is called transesterification. The problem with the transestrification refining method is that it is relatively expensive and produces a quantity of glycerin byproduct that has to be processed again before it has any value. The final fuel product has detergent qualities that can clean out existing fuel tanks and the resulting debris is prone to clog fuel filters for a while.

So, to reduce oil viscosity in a less expensive and much lesser time consuming way, addition of solvent preferably Alkyl-benzene is done by the author. This is because addition of Alkyl-benzene reduces the density of the oil and thus decreases the oil viscosity. The purpose of making a solvent blended biofuel is to thin the resulting blended oil to near the viscosity of diesel oil and reduce its gel-point. The resulting solution should be a uniform solution without precipitates.

Vegetable oils are an attractive renewable source for alternative diesel fuels. However, the relatively high kinematic viscosity of vegetable oils must be reduced to make them more compatible with conventional compression-ignition engines and fuel systems. Cosolvent blending is a low-cost and easy-to-adapt technology that reduces viscosity (and gel point) by diluting the vegetable oil with a low-(molecular weight solvent), which is in our case is Methyl-benzene(Toluene).

Blending methods vary; however, the most common method of making Blended Biofuels Diesel (BBD) is to blend the solvent with the source vegetable oil because blending solvents with vegetable oils has three basic functions. Blending reduces the viscosity of the source oil, reduces its gel-point, and tends to force water, and other contaminants, out of solution. This means that thinned oil will drop its contaminant load much more quickly than the more viscous source oil.

3.3 Mud Formulation of Base Fluid

Before rheology test commence, mud formulation should be done for each base fluid that going to be tested.

Composition	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Saraline 185V, lb/bbl	184						
Methyl Esther Palm Oil	-	210					
Sesame Oil	-	-	220	220	220	220	220
Toluene	-	-	-	20	25	35	40
VERSAPRO, lb/bbl	7	7	7	7	7	7	7
VERSAGEL®, lb/bbl	6	6	6	6	6	6	6
LIME®, lb/bbl	3	3	3	3	3	3	3
VERSATROL, lb/bbl	7	7	7	7	7	7	7
Water, bbl	59	59	68.5	68.5	68.5	68.5	68.5
$CaCl_2$, lb/bbl	20.9	20.9	13.4	13.4	13.4	13.4	13.4
MIL-BAR®, lb/bbl	128.4	128.4	1.8	1.8	1.8	1.8	1.8

Table 3 : Mud Fourmulation

3.4 *ASTM Standards:* D471 Test Methods for Rubber Property Effect of Liquids

Besides that, the compatibility of Sesame oil with elastomers will also be tested. Elastomers are developed and selected for mechanical performance with environmental interactions secondary. The properties of elastomers are presented before and after sesame oil based mud exposure. The property changes were evaluated with respect to equipment function and performance and exposure time. This test procedure measures the ability of rubber to withstand the effect of liquids. It is designed for testing specimens of elastomeric vulcanizates cut from standard sheets.

3.5 Required Tools

Equipments:

1) Multi Mixer
2) FANN Model 35
3) HTHP filter press
4) Electric Stability Meter
5) Basic equipments in lab such as beaker,heater,3 neck flask, separator funnel, and thermometer, stopwatch

Consumables:

1) Crude Sesame Oil, Saraline 185V, Methyl Ester Palm Oil, Methyl-benzene.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. RHEOLOGICAL TEST RESULTS

Table 4.1 shows the mud properties results after rheology test were applied to Sesame Oil, Methyl Ester Palm Oil and Saraline.

Test 1 = Saraline Oil
Test 2 = Methyl Ester Palm Oil
Test 3 = Sesame Oil
Test 4 = Sesame Oil with 20g Toluene
Test 5 = Sesame Oil with 25g Toluene
Test 6 = Sesame Oil with 35g Toluene
Test 7 = Sesame Oil with 40g Toluene

Formulation	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Mud weight (ppg)	10	10	12	12	12	12	12
Rheology Temperature (◦F)	75	75	75	75	75	75	75
600 rpm	54	79	300+	210	180	177	154
300 rpm	37	54	300+	130	110	108	95
200 rpm	21	28	239	96	71	69	32
100 rpm	16	19	178	59	45	42	38
6 rpm	8	7	76	22	10	9	7
3 rpm	7	5	54	13	8	5	2
Plastic Viscosity, cP	17	25	-	80	70	68	59
Yield Point, lb/100 ft2	20	29	-	50	40	39	36
Gels, 10 sec	10	14	55	29	12	10	8
Gels, 10 min	13	16	71	37	18	16	14

Table 4: Rheology Test Result

Major comparisons are done between Sesame Oil, Methyl Ester Palm Oil and Saraline Oil is their Plastic Viscosity and Yield Point. Experiment showed that Saraline Oil has lower PV and YP and preferable value of Electrical Stability and Gel Strength as well. These criteria are more suitable and compatible to be used as base fluid. Commercial factor is the outmost possible reason why it is still the best base fluid to be used.

4.1.1 Plastic Viscosity

Base Fluid	Sesame Oil with 40 Toluene	Methyl Ester Palm Oil	Saraline Oil
Plastic Viscosity, cp	**59**	**25**	**17**

Table 5: Plastic Viscosity

4.1.2 Yield Point

Base Fluid	Sesame Oil with 40 Toluene	Methyl Ester Palm Oil	Saraline Oil
Yield Point, b/100 ft^2	**36**	**29**	**20**

Table 6: Yield Point

Graph 1: Plastic Viscosity and Yield Point

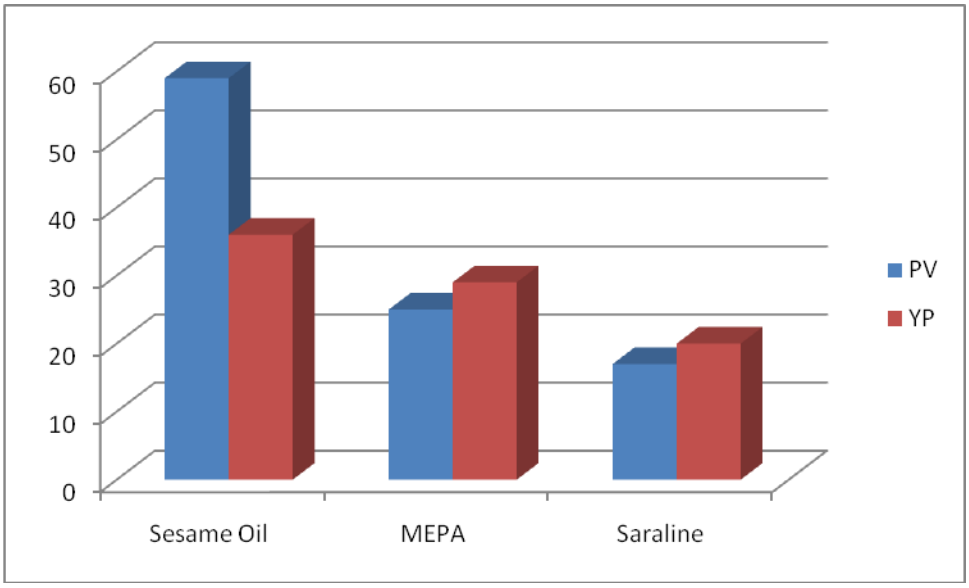

Figure 3: Graph of Plastic Viscosity of Base Fluid

Graph II: Gel Strength

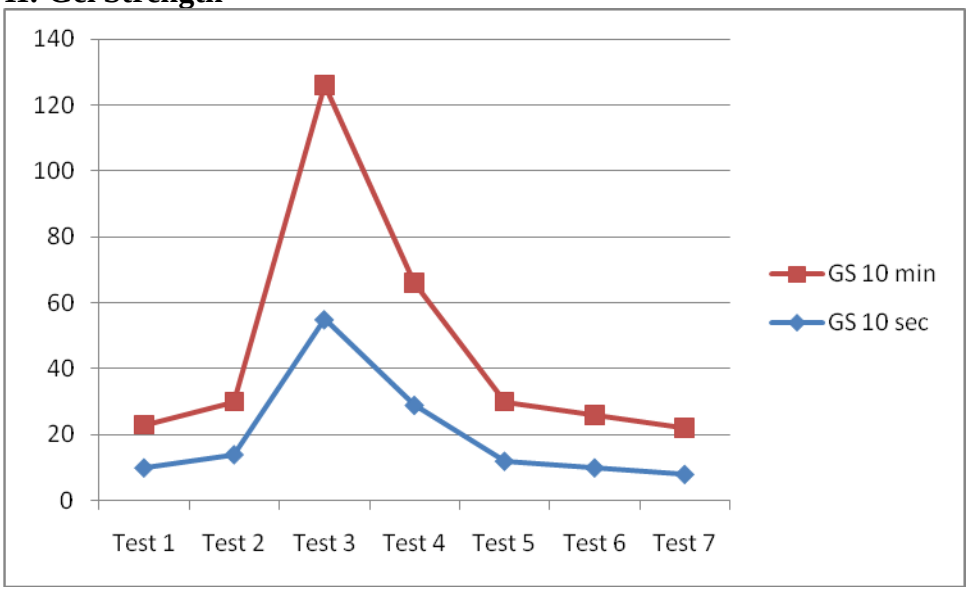

Figure 4: Graph of Yield Point of Base Fluid

Graph III: Electrical Stability

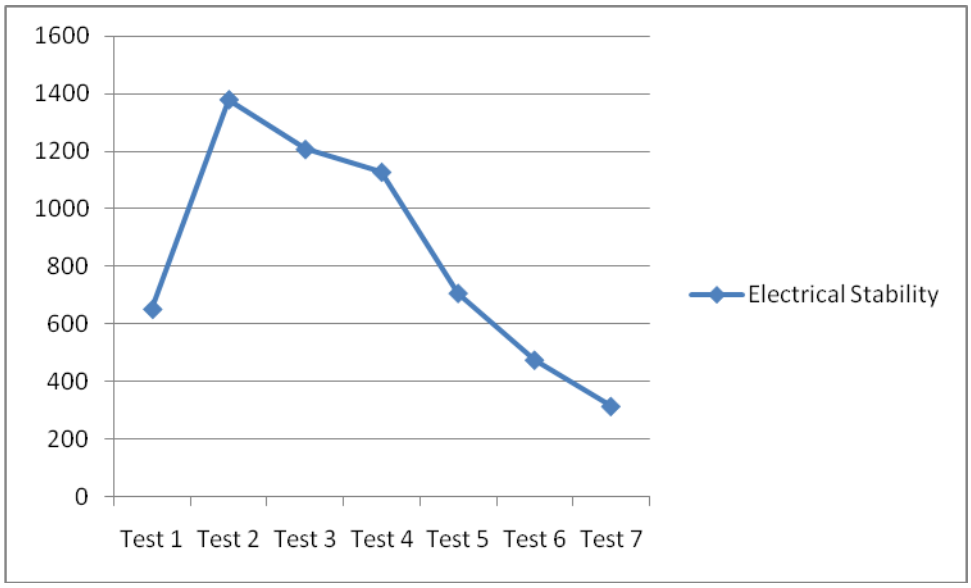

Figure 5: Graph of Electrical stability of Base Fluid

Graph IV: Filtration Loss

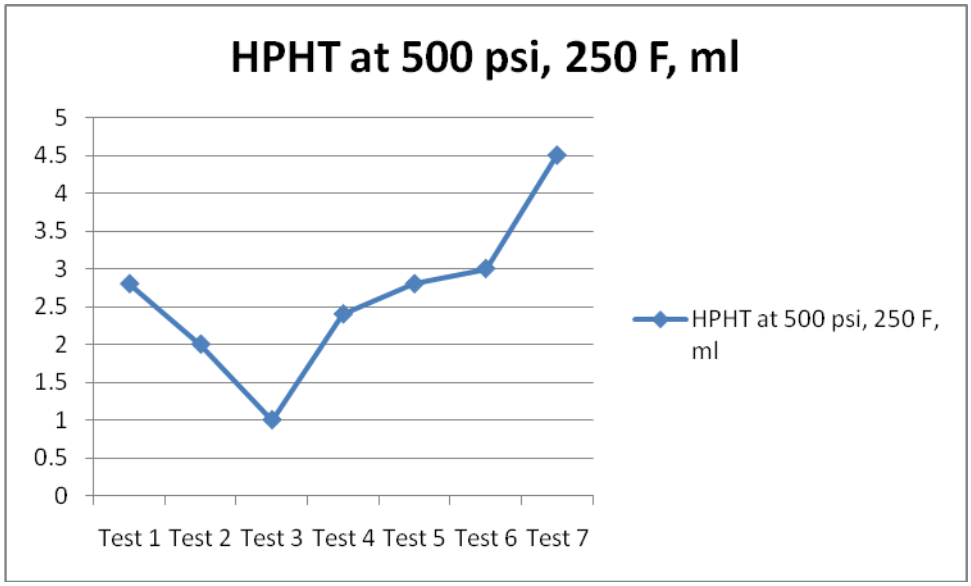

Figure 6: Graph of Yield Point of Base Fluid

Discussion

From the rheology test result, it shows that sesame oil has high plastic viscosity and yield point but has preferable value of electrical stability and gel strength. This shows that sesame oil did not attain the properties of base fluid for drilling operation. Methyl ester palm oil instead shows a better properties compared to sesame oil because it has lower value of plastic viscosity but high yield point and quite good value of electrical stability and gel strength as well. All base fluid properties were compared between saraline oil, methyl ester palm oil and sesame oil. The result shows that saraline oil is still incomparable.

4.2 Economic Analysis

The successful completion of an oil well and its cost is depend to a considerable extent on the properties of the drilling fluid. The cost of the drilling fluid itself is relatively small, but the choice of the right fluid and maintenance of the right properties while drilling greatly influence the total well costs. Drilling means money, therefore each and every decision taken in oil and gas industry must be very careful and effectively to the industry. This project is mainly about choosing the right drilling fluid in drilling operation in order to have a successful completion of a well.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The outmost aim of the project to study the effectiveness and compatibility of sesame oil as a base fluid is achieved by comparison with conventionally used base oil, which is mineral oil Saraline. The comparative study that covered physical characteristics and elastomeric effect clearly pointed out few important things.

- Viscosity of sesame oil has been reduced by simple chemical blending with Toluene.

- Rheology study of sesame oil and Saraline are done.

- Based on rheology study, the plastic viscosity of Saraline is lower than that of sesame oil but addition of Toluene minimized the gap.

By comparing vegetable oil and mineral oil, mineral oil is still the best to be used as based fluid in drilling operation as mineral oil is also less harmful to the environment. When Sesame Oil is compared with Saraline Oil which also can be mentioned as comparing between vegetable oil and mineral oil, mineral oil shows a better base fluid characteristic to be use in drilling operation. The reason why mineral oil is far better compare to vegetable oil is Saraline is specially engineered to be used for commercial purpose in drilling fluid. Therefore, it definitely will show a most convincing result than the other two of the vegetable oil.

5.2 Recommendation

At the end of laboratory work, it is identified that sesame Oil is not asuitable base oil to be commercialized as base fluid for drilling operation at the moment. This conclusion has been made after the author had gone through some research and literature review. At the same time, Methyl Ester Palm Oil and Saraline Oil still a good candidates to replace diesel due to some concern like environmental impact and stock availability.

Biodiesel based fluid is an excellent alternative for diesel. It has good characteristics in terms of rheological behavior as well as environmental concern. Thus, this kind of based fluid should be further explored. During the experiments, there might some error in order to complete and strive for the objective especially during the viscosity reduction process. The author used Toluene as the diluter as it is the only suitable chemical to dilute other liquid that is available in the laboratory. This simple chemical blending to reduce the viscosity of sesame oil might not be the best procedure. With the limitation of chemical and equipments, it might be the main reason why drilling fluid produced with sesame oil as the main based fluid did not show a convenience result as compared to Saraline Oil and Methyl Ester Palm Oil.

In conclusion, the recommendation for this project is to have clean and appropriate procedure and methodology to convert Sesame Oil into Sesama Oil FAME with the aim of better rheology test result. This required further studies on the best equipments, chemicals and additives to be used. Hopefully, sesame oil fatty acid methyl ester might be a better candidate to replace diesel oil in drilling operation.

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APPENDIX

Appendix 1- Saraline 185V

Typical Chemical Properties	Property	Unit	Value	Test Method
	C10 & Lower	%m/m	1.8	GC x GC
	C11-C14	%m/m	28.5	GC x GC
	C15-C18	%m/m	40.8	GC x GC
	C19-C20	%m/m	21.1	GC x GC
	C21 & Higher	%m/m	7.8	GC x GC
	Total Paraffin	%m/m	99.2	GC x GC

Typical Physical Properties	Property	Value	Test Method
	Physical state	Liquid at ambient temperature.	
	Saybolt Colour	30+	ASTM D156
	Odour	Odourless	

Typical Physical Properties	Property	Unit	Value	Test Method
	Boiling Range			ASTM D86
	IBP	°C	206	
	90% recovered	°C	308	
	FBP	°C	318	
	Vapour pressure @40°C	kPa	<0.1	Calculated
	Density @ 15°C	kg/m^3	778	ASTM D1298
	Kinematic viscosity @ 40°C	mm^2/s	2.6	ASTM D445
	Vapour density (air=1)		> 5	
	Sulphur	ppm	< 3	ASTM D3120
	Aromatic	%m	< 0.1	SMS 2728
	Pour point	°C	-21	ASTM D97
	Cloud point	°C	-14	ASTM D2500
	Flash point	°C	89	ASTM D93
	Aniline Point	°C	95	ASTM D611
	Auto-ignition point	°C	216	ASTM E659
	Fire point	°C	114	ASTM D92
	Solubility in water		Insoluble	
	Copper corrosion 3 hrs at 100°F		1a	ASTM D130

Typical Environmental Properties

Property	Test protocol	Value	Toxicity classification
Biodegradation			
Aerobic	OECD 306 28-d	62%	Biodegrades
Water Column Toxicity		(mg/l, SPP)	
Mysidopsis bahia[1]	96-hr LC_{50}	>1,000,000	Non-toxic
T. mossambica[2]	96-hr LC_{50}	145,000	Non-toxic
Mugil persia[2]	96-hr LC_{50}	98,000	Almost non-toxic
Mugil cephalus[2]	96-hr LC_{50}	86,500	Almost non-toxic
Penaeus indicus[2]	96-hr LC_{50}	67,000	Almost non-toxic
Pagrus auratus[2]	96-hr LC_{50}	>100,000	Non-toxic
Nitzschia closterium[3]	72-hr EC_{50}	>83,300	Almost Non-toxic
Pagrus auratus[4]	72-hr EC_{50}	>100,000	Non-toxic
Sediment toxicity			
Corophium volutator	10-d LC_{50}	>50,000 mg/kg (dry)	Non-toxic
Boleopthalmus boddarti	10-d LC_{50}	235,000 mg/l	Non-toxic
Scylla serrata	10-d LC_{50}	128,000 mg/l	Non-toxic
Partition coefficient			
OECD 117	Log P_{ow}	>6.5	Do not readily bioaccumulate if <2 or >6[5]

Storage and Handling

Shell GTL Saraline 185V may be stored in mild steel or stainless steel tanks. Seals and gaskets may be made from compressed asbestos fibre, PTFE, Viton A and Viton B. Natural rubbers, PVC, polystyrene and copper alloys are unsuitable materials for use with Shell GTL Saraline 185V. The recommended storage and handling temperature is between 15 and 45°C.

Hazard Identification

Shell GTL Saraline 185V has a relatively low order of toxicity by the routes of exposure (oral, dermal, inhalation) encountered in normal handling. Like many hydrocarbon liquids, Shell GTL Saraline 185V will dry and de-fat the skin on prolonged contact and on repeated contact could result in skin irritation and dermatitis. Also, like other hydrocarbons, this product can be dangerous when aspirated or ingested.

Before handling the product, refer to the Material Safety Data Sheet.

Appendix 2 – Technical properties of biodiesel

Technical properties	Description
Common name	Biodiesel (bio-diesel)
Common chemical name	Fatty acid (m)ethyl ester
Chemical formula range	$C_{14} - C_{24}$ methyl ester or $C_{15} - C_{25}$ H_{28-48} O_2
Kinematic viscosity range (mm^2/s, at 313K)	3.3 – 5.2
Density range (kg/m^3, at 288K)	860 – 894
Boiling point range (K)	>475
Flash point range (K)	430 – 455
Distillation range (K)	470 – 600
Vapour pressure (mm Hg, at 295K)	<5
Solubility in water	Insoluble in water
Physical appearance	Light to dark yellow, clear liquid
Odor	Light musty or soapy odor
Biodegradability	More biodegradable than petroleum diesel
Reactivity	Stable but avoid strong oxidation agents

Appendix 3 – Density Measurement

Table 1.0: Density Measurement for Mineral Based Oil (100%)

Pressure	300°F	275°F	250°F	225°F	200°F	175°F	150°F	120°F	100°F	80.6°F
50	0.6015	0.6239	0.6449	0.6668	0.6818	0.6965	0.7092	0.7270	0.7330	0.7481
500	0.6058	0.6279	0.6483	0.6697	0.6848	0.6994	0.7118	0.7293	0.7355	0.7506
1000	0.6105	0.6317	0.6518	0.6729	0.6885	0.7021	0.7144	0.7318	0.7380	0.7530
1500	0.6147	0.6346	0.6552	0.6761	0.6917	0.7049	0.7172	0.7345	0.7405	0.7554
2500	0.6222	0.6416	0.6617	0.6822	0.6973	0.7110	0.7226	0.7397	0.7455	0.7602
5000	0.6385	0.6570	0.6756	0.6962	0.7109	0.7240	0.7353	0.7514	0.7570	0.7710

Table 1.1: Specific Volume (cc/g) for Mineral Based Oil (100%)

Pressure	300°F	275°F	250°F	225°F	200°F	175°F	150°F	120°F	100°F	80.6°F
50	1.662510391	1.602821	1.550628	1.4997	1.466706	1.43575	1.410039	1.375516	1.364256	1.33672
500	1.650709805	1.59261	1.542496	1.493206	1.46028	1.429797	1.404889	1.371178	1.359619	1.332268
1000	1.638001638	1.58303	1.534213	1.486105	1.452433	1.424299	1.399776	1.366494	1.355014	1.328021
1500	1.626809826	1.575796	1.526252	1.479071	1.445713	1.418641	1.394311	1.36147	1.350439	1.323802
2500	1.607200257	1.558603	1.511259	1.465846	1.434103	1.40647	1.383892	1.351899	1.341382	1.315443
5000	1.566170713	1.52207	1.480166	1.436369	1.406668	1.381215	1.359989	1.330849	1.321004	1.297017

Table 1.2: Compressibility (Reference First Specific Volume) for Mineral Based Oil (100%)

Pressure	300°F	275°F	250°F	225°F	200°F	175°F	150°F	120°F	100°F	80.6°F
50	0	0	0	0	0	0	0	0	0	0
500	1.57734E-05	1.42E-05	1.17E-05	9.62E-06	9.74E-06	9.21E-06	8.12E-06	7.01E-06	7.55E-06	7.4E-06
1000	1.55179E-05	1.3E-05	1.11E-05	9.54E-06	1.02E-05	8.4E-06	7.66E-06	6.9E-06	7.13E-06	6.85E-06
1500	1.48096E-05	1.16E-05	1.08E-05	9.49E-06	9.87E-06	8.22E-06	7.69E-06	7.04E-06	6.99E-06	6.66E-06
2500	1.35792E-05	1.13E-05	1.04E-05	9.21E-06	9.07E-06	8.32E-06	7.57E-06	7.01E-06	6.84E-06	6.5E-06
5000	1.17067E-05	1.02E-05	9.18E-06	8.53E-06	8.27E-06	7.67E-06	7.17E-06	6.56E-06	6.4E-06	6E-06

Table 1.3: Thermal Exp. Coefficient for Mineral Based Oil (100%)

Pressure	300°F	275°F	250°F	225°F	200°F	175°F	150°F	120°F	100°F	80.6°F
50	0.001111	0.001024	0.000945	0.000844	0.000814	0.000785	0.000790	0.000737	0.001062	0
500	0.001089	0.001005	0.000932	0.000837	0.000805	0.000775	0.000785	0.000741	0.001058	0
1000	0.001064	0.000988	0.000917	0.000824	0.000785	0.000768	0.000779	0.000735	0.001048	0
1500	0.001043	0.000979	0.000903	0.000812	0.000771	0.000759	0.000767	0.000722	0.001037	0
2500	0.001011	0.000951	0.000879	0.000792	0.000755	0.000733	0.000750	0.000703	0.001016	0
5000	0.000946	0.000893	0.000834	0.000744	0.000708	0.000688	0.000700	0.000662	0.000953	0

Table 2.0: Density measurement for Vegetable and Mineral Based Oil (50%/50%)

Pressure	300°F	275°F	250°F	225°F	200°F	175°F	150°F	120°F	100°F	80.6°F
50	0.6471	0.6633	0.6823	0.7016	0.7123	0.7170	0.7367	0.7605	0.7759	0.7859
500	0.6509	0.6662	0.6857	0.7050	0.7153	0.7206	0.7388	0.7629	0.7782	0.7881
1000	0.6550	0.6700	0.6891	0.7085	0.7185	0.7237	0.7414	0.7650	0.7807	0.7907
1500	0.6590	0.6738	0.6926	0.7118	0.7216	0.7268	0.7442	0.7676	0.7833	0.7931
2500	0.6664	0.6807	0.6989	0.7179	0.7276	0.7323	0.7495	0.7726	0.7884	0.7978
5000	0.6822	0.6964	0.7129	0.7317	0.7406	0.7447	0.7619	0.7848	0.7998	0.8088

Table 2.1: Specific Volume (cc/g) for Vegetable and Mineral Based Oil (50%/50%)

Pressure	300°F	275°F	250°F	225°F	200°F	175°F	150°F	120°F	100°F	80.6°F
50	1.545356205	1.507613	1.465631	1.425314	1.403903	1.3947	1.357405	1.314924	1.288826	1.272427
500	1.536334306	1.501051	1.458364	1.41844	1.398015	1.387732	1.353546	1.310788	1.285017	1.268875
1000	1.526717557	1.492537	1.451168	1.411433	1.391788	1.381788	1.3488	1.30719	1.280902	1.264702
1500	1.517450683	1.48412	1.443835	1.404889	1.385809	1.375894	1.343725	1.302762	1.27665	1.260875
2500	1.50060024	1.469076	1.43082	1.392952	1.374382	1.365561	1.334223	1.294331	1.268392	1.253447
5000	1.465845793	1.435956	1.402721	1.36668	1.350257	1.342823	1.312508	1.27421	1.250313	1.2364

Table 2.2: Compressibility (Reference First Specific Volume) for Vegetable and Mineral Based Oil (50%/50%)

Pressure	300°F	275°F	250°F	225°F	200°F	175°F	150°F	120°F	100°F	80.6°F
50	0	0	0	0	0	0	0	0	0	0
500	1.29735E-05	9.67E-06	1.1E-05	1.07E-05	9.32E-06	1.11E-05	6.32E-06	6.99E-06	6.57E-06	6.2E-06
1000	1.26959E-05	1.05E-05	1.04E-05	1.03E-05	9.08E-06	9.75E-06	6.67E-06	6.19E-06	6.47E-06	6.39E-06
1500	1.24536E-05	1.07E-05	1.03E-05	9.88E-06	8.89E-06	9.3E-06	6.95E-06	6.38E-06	6.52E-06	6.26E-06
2500	1.18211E-05	1.04E-05	9.69E-06	9.27E-06	8.58E-06	8.53E-06	6.97E-06	6.39E-06	6.47E-06	6.09E-06
5000	1.03942E-05	9.6E-06	8.67E-06	8.31E-06	7.72E-06	7.51E-06	6.68E-06	6.26E-06	6.04E-06	5.72E-06

Table 2.3: Thermal Exp. Coefficient for Vegetable and Mineral Based Oil (50%/50%)

Pressure	300°F	275°F	250°F	225°F	200°F	175°F	150°F	120°F	100°F	80.6°F
50	0.000978	0.000951	0.000896	0.000832	0.000865	0.001018	0.000962	0.000848	0.000664	0
500	0.000961	0.000941	0.000882	0.000816	0.000852	0.000992	0.000962	0.000838	0.000656	0
1000	0.000944	0.000927	0.000870	0.000803	0.000842	0.000981	0.000958	0.000853	0.000660	0
1500	0.000927	0.000911	0.000857	0.000791	0.000830	0.000966	0.000947	0.000843	0.000645	0
2500	0.000899	0.000885	0.000835	0.000771	0.000808	0.000948	0.000929	0.000828	0.000615	0
5000	0.000846	0.000830	0.000794	0.000730	0.000771	0.000912	0.000887	0.000776	0.000580	0

Table 3:0: Density measurement for Vegetable Based Oil (100%)

Pressure	300°F	275°F	250°F	225°F	200°F	175°F	150°F	120°F	100°F	80.6°F
50	0.6874	0.7064	0.7243	0.7465	0.7510	0.7686	0.7838	0.8106	0.8206	0.8330
500	0.6915	0.7102	0.7275	0.7488	0.7542	0.7711	0.7866	0.8133	0.8234	0.8353
1000	0.6956	0.7139	0.7312	0.7519	0.7575	0.7736	0.7895	0.8161	0.8262	0.8378
1500	0.6996	0.7175	0.7347	0.7545	0.7605	0.7764	0.7922	0.8187	0.8289	0.8404
2500	0.7069	0.7243	0.7413	0.7601	0.7664	0.7819	0.7974	0.8238	0.8341	0.8449
5000	0.7225	0.7389	0.7560	0.7736	0.7795	0.7945	0.8095	0.8358	0.8457	0.8559

Table 3.1: Specific Volume (cc/g) for Vegetable Based Oil (100%)

Pressure	300°F	275°F	250°F	225°F	200°F	175°F	150°F	120°F	100°F	80.6°F
50	1.454757	1.415629	1.380643	1.339585	1.331558	1.301067	1.275836	1.233654	1.218621	1.20048
500	1.446132	1.408054	1.37457	1.33547	1.325908	1.296849	1.271294	1.229559	1.214477	1.197175
1000	1.437608	1.400756	1.367615	1.329964	1.320132	1.292658	1.266624	1.22534	1.210361	1.193602
1500	1.429388	1.393728	1.3611	1.325381	1.314924	1.287996	1.262307	1.221449	1.206418	1.18991
2500	1.414627	1.380643	1.348982	1.315616	1.304802	1.278936	1.254076	1.213887	1.198897	1.183572
5000	1.384083	1.353363	1.322751	1.292658	1.282874	1.258653	1.23533	1.196458	1.182452	1.168361

Table 3.2: Compressibility (Reference First Specific Volume) for Vegetable Based Oil (100%)

Pressure	300°F	275°F	250°F	225°F	200°F	175°F	150°F	120°F	100°F	80.6°F
50	0	0	0	0	0	0	0	0	0	0
500	1.32E-05	1.19E-05	9.77E-06	6.83E-06	9.43E-06	7.2E-06	7.91E-06	7.38E-06	7.56E-06	6.12E-06
1000	1.24E-05	1.11E-05	9.93E-06	7.56E-06	9.03E-06	6.8E-06	7.6E-06	7.09E-06	7.13E-06	6.03E-06
1500	1.2E-05	1.07E-05	9.76E-06	7.31E-06	8.62E-06	6.93E-06	7.31E-06	6.82E-06	6.91E-06	6.07E-06
2500	1.13E-05	1.01E-05	9.36E-06	7.3E-06	8.2E-06	6.94E-06	6.96E-06	6.54E-06	6.61E-06	5.75E-06

Appendix 4 – Recommended practice standard procedure for field testing oil-based drilling fluids(1998), American Petroleum Institute.

Recommended Practice for Field Testing of Oil-based Drilling Fluids

1 Scope

This Recommended Practice provides standard procedures for determining the following characteristics of oil-based drilling fluids:

a) drilling fluid density (mud weight);

b) viscosity and gel strength;

c) filtration;

d) oil, water and solids contents;

e) alkalinity, chloride content and calcium content;

f) electrical stability;

g) lime and calcium contents, calcium chloride and sodium chloride contents;

h) low-gravity solids and weighting material contents.

Annexes A, B, C, D, H, I, K and L provide additional test methods that may optionally be used for the determination of

i) shear strength,

j) oil and water contents from cuttings,

k) drilling fluid activity,

l) aniline point,

m) cuttings activity,

n) active sulfides.

o) PPA test method for cells with set screws.

p) PPA test method for cells with screw-on caps.

Annexes F, G and J provide procedures that may optionally be used for

q) sampling, inspection and rejection,

r) rig-site sampling,

s) calibration and verification of glassware, thermometers, viscometers, retort kit cups and drilling fluid balances.

Annex E provides examples of calculations for

t) lime, salinity and solids content.

Annex M contains an example of a drilling fluid report form.

2 Terms and definitions

For the purposes of this Standard, the following term and definition applies:

2.1
ACS reagent grade
grade of chemical meeting the purity standards specified by the American Chemical Society (ACS)

2.2
API
American Petroleum Institute, 1220 L Street NW, Washington, DC 20005

2.3
CAS
Chemical Abstracting Service

2.4
USC
United States Customary unit, shown in parentheses following SI unit

3 Abbreviations

ACS	American Chemical Society
BAD	Base alkalinity demand
EDTA	eithylenediaminetetraacetic acid
ES	electrical stability
HT/HP	high temperature, high pressure
OCMA	Oilfield Chemical Manufacturer's Association
PNP	propylene glycol normal-propyl ether
PTFE	polytetrafluoreoethylene, brand name Teflon®
TC	to contain
TD	to deliver
R_{300}	viscometer reading at 300 r/min
R_{600}	viscometer reading at 600 r/min
?	static filtration rate

m_1 mass of retort cup, lid and body with steel wool, g

m_2 mass of retort cup, lid, body and cuttings, g

m_3 mass of empty liquid receiver, g

m_4 mass of liquid receiver and fluid collected during solids analysis, g

m_5 mass of solids remaining in retort cup following solids analysis, g

R static filtration rate

V volume of liquid collected in receiver, ml

V_o volume of oil, cm^3

V_s volume of solids, cm^3

V_1 volume of filtrate after 7,5 min, cm^3

V_2 volume of filtrate after 30 min, cm^3

V_w volume of water, cm^3

η_P viscosity of plastic viscosity

η_Y viscosity of yield point

η_A appararent viscosity

φ_o volume fraction of oil

φ_s volume fraction of solids

φ_w volume fraction of water

ρ density

$\nabla\rho$ density gradient

4 Determination of drilling fluid density (mud weight)

4.1 Principle

A procedure is given for determining the mass of a given volume of liquid (= density). The density of drilling fluid is expressed as grams per cubic centimetre, kilograms per cubic metre, pounds per gallon or pounds per cubic foot.

4.2 Apparatus

a) Any **density-measuring instrument** having an accuracy of ± 0,01 g/cm^3, ± 10 kg/m^3, ± 0,1 lb/gal, or ± 0,5 lb/ft^3.

The mud balance is the instrument generally used for drilling fluid density determinations. The mud balance is designed such that the drilling fluid holding cup, at one end of the beam, is balanced by a fixed counterweight at the other end, with a sliding-weight rider free to move along a graduated scale. A level-bubble is mounted on the

beam to allow for accurate balancing. Attachments for extending the range of the balance may be used when necessary.

The instrument should be calibrated frequently with fresh water. Fresh water should give a reading of 1,00 g/cm^3 or 1 000 kg/m^3 at 21 °C (70 °F). If it does not, adjust the balancing screw or the amount of lead shot in the well at the end of the graduated arm as required.

b) **Thermometer**, with a range of 0 °C to 105 °C (32 °F to 220 °F).

4.3 Procedure

4.3.1 The instrument base should be set on a flat, level surface.

4.3.2 Measure the temperature of the drilling fluid and record.

4.3.3 Fill the clean, dry cup with drilling fluid to be tested; put the cap on the filled drilling-fluid holding cup and rotate the cap until it is firmly seated. Ensure that some of the drilling fluid is expelled through the hole in the cap, in order to free any trapped air or gas.

4.3.4 Holding the cap firmly on the drilling-fluid holding cup (with cap hole covered), wash or wipe the outside of the cup clean and dry.

4.3.5 Place the beam on the base support and balance it by moving the rider along the graduated scale. Balance is achieved when the bubble is under the centreline.

4.3.6 Read the drilling fluid density at the edge of the rider toward the drilling-fluid cup. Make appropriate corrections when a range extender is used.

4.4 Calculation

4.4.1 Report the drilling fluid density, ρ_s, to the nearest 0,01 g/cm^3 , 10 kg/m^3, 0,1 lb/gal or 0,5 lb/ft^3.

4.4.2 To convert the reading to other units, use the following:

$$\rho_s = 1\ 000 \times \text{g/cm}^3 \quad (1)$$

$$\rho_s = 16 \times \text{lb/ft}^3 \quad (2)$$

$$\rho_s = 119{,}8 \times \text{lb/US gal} \quad (3)$$

where ρ_s is the density, expressed in kilograms per cubic metre.

$$\nabla\rho_s = 9{,}81 \times \text{g/cm}^3 \quad (4)$$

$$\nabla\rho_s = 0{,}0226 \times \text{psi/1 000 ft} \quad (5)$$

where $\nabla\rho_s$ is the drilling fluid density gradient, expressed in kilopascals per metre.

A list of density conversions from SI to USC units is given in Table 1.

Table 1 — Density conversions between SI and USC units

Grams per cubic centimetre[a] g/cm^3	Kilograms per cubic metre kg/m^3	Pounds per US gallon (lb/US gal)	Pounds per cubic foot (lb/ft^3)
0,70	700	5,8	43,6
0,80	800	6,7	49,8
0,90	900	7,5	56,1
1,00	1 000	8,345[b]	62,3
1,10	1 100	9,2	68,5
1,20	1 200	10,0	74,8
1,30	1 300	10,9	81,0
1,40	1 400	11,7	87,2
1,50	1 500	12,5	93,5
1,60	1 600	13,4	99,7
1,70	1 700	14,2	105,9
1,80	1 800	15,0	112,1
1,90	1 900	15,9	118,4
2,00	2 000	16,7	124,6
2,10	2 100	17,5	130,8
2,20	2 200	18,4	137,1
2,30	2 300	19,2	143,3
2,40	2 400	20,0	149,5
2,50	2 500	20,9	155,8
2,60	2 600	21,7	162,0
2,70	2 700	22,5	168,2
2,80	2 800	23,4	174,4
2,90	2 900	24,2	180,7

[a] Same value as relative density.
[b] Accurate conversion factor.

5 Alternative method for determination of drilling fluid density

5.1 Principle

5.1.1 The pressurized mud balance provides a more accurate method for determining the density of a drilling fluid containing entrained air or gas than does the conventional mud balance. The pressurized mud balance is similar in operation to the conventional mud balance, the difference being that the slurry sample is placed in a fixed-volume sample cup under pressure.

5.1.2 The purpose of placing the sample under pressure is to minimize the effect of entrained air or gas upon slurry density measurements. By pressurizing the sample cup, any entrained air or gas is decreased to a negligible volume, thus providing a slurry density measurement more closely in agreement with that obtained under downhole conditions.

5.2 Apparatus

a) Any **density-measuring instrument** having an accuracy of ± 0,01 g/cm^3, ± 10 kg/m^3, ± 0,1 lb/gal, or ± 0,5 lb/ft^3.

The pressurized mud balance is the instrument generally used for density determinations of pressurized drilling fluids. The pressurized mud balance is designed such that the drilling-fluid holding cup and screw-on lid, at one end of the beam, is balanced by a fixed counterweight at the other end, with a sliding-weight rider free to move along a graduated scale. A level-bubble is mounted on the beam to allow for accurate balancing.

Calibrate the instrument frequently with fresh water. Fresh water should give a reading of 1,0 g/cm^3 or 1 000 kg/m^3 at 21 °C (69,8 °F). If it does not, adjust the balancing screw or the amount of lead shot in the well at the end of the graduated arm as required.

b) **Thermometer**, with a range of 0 °C to 105 °C (32 °F to 220 °F).

5.3 Procedure

5.3.1 Measure the temperature of the drilling fluid and record.

5.3.2 Fill the sample cup to a level slightly (approximately 6 mm) below the upper edge of the cup.

5.3.3 Place the lid on the cup with the attached check-valve in the down (open) position. Push the lid downward into the mouth of the cup until surface contact is made between the outer skirt of the lid and the upper edge of the cup. Any excess slurry will be expelled through the check-valve. When the lid has been placed on the cup, pull the check-valve up into the closed position, rinse off the cup and threads with water, and screw the threaded cap on the cup.

5.3.4 The pressurizing plunger is similar in operation to a syringe. Fill the plunger by submersing its end in the slurry with the piston rod completely inside. Then draw the piston rod upward, thereby filling the cylinder with slurry. This volume should be expelled with the plunger action and refilled with fresh slurry sample to ensure that this plunger volume is not diluted with liquid remaining from the last clean-up of the plunger mechanism.

5.3.5 Push the nose of the plunger onto the mating O-ring surface of the cap valve. Pressurize the sample cup by maintaining a downward force on the cylinder housing in order to hold the check-valve down (open) and at the same time to force the piston rod inside. A force of approximately 225 N (50 lbf) or greater should be maintained on the piston rod.

5.3.6 The check-valve in the lid is pressure-actuated; when the inside of the cup is pressurized, the check-valve is pushed upward into the closed position. To close the valve gradually ease up on the cylinder housing while maintaining pressure on the piston rod. When the check-valve closes, release pressure on the piston rod before disconnecting the plunger.

5.3.7 The pressurized slurry sample is now ready for weighing. Rinse the exterior of the cup and wipe dry. Place instrument on the knife edge. Move the sliding weight right or left until the beam is balanced. The beam is balanced when the attached bubble is centred between the two black marks. Read the density from one of the four calibrated scales on the arrow side of the sliding weight. The density can be read directly in units of grams per cubic centimetre, pounds per gallon, and pounds per cubic foot, or as a drilling fluid gradient in pounds per square inch per 1 000 feet.

5.3.8 To release the pressure inside the cup, reconnect the empty plunger assembly and push downward on the cylinder housing.

5.3.9 Clean the cup and rinse thoroughly with base oil.

5.4 Calculation

Report the drilling fluid density to the nearest 0,01 g/cm^3 , 10 kg/m^3, 0,1 lb/gal, or 0,5 lb/ft^3.

For conversions, use the formulas given in 4.4.2.

6 Viscosity and gel strength

6.1 Principle

Viscosity and gel strength are measurements that relate to the flow properties (rheology) of drilling fluids. The following instruments are used to measure viscosity and/or gel strength of drilling fluids:

a) Marsh funnel — a simple device for indicating viscosity on a routine basis;

b) direct-indicating viscometer — a mechanical device for measurement of viscosity at varying shear rates.

NOTE Information on the rheology of drilling fluids can be found in API RP 13D.

6.2 Determination of viscosity using the Marsh funnel

6.2.1 Apparatus

a) **Marsh funnel**, calibrated to deliver 946 cm^3 (1 quart) of fresh water at a temperature of 21 ± 3 °C (70 ± 5 °F) in 26 ± 0,5 s, with a graduated cup as a receiver.

The Marsh funnel shall have the following characteristics:

1) **funnel cone**, length 305 mm (12,0 in), diameter 152 mm (6,0 in) and a capacity to bottom of screen of 1 500 cm^3 (1,6 quarts);

2) **orifice**, length 50,8 mm (2,0 in) and inside diameter 4,7 mm (0,185 in);

3) **screen**, with 1,6 mm (0,063 in) openings (12 mesh); fixed at 19,0 mm (0,748 in) below top of funnel.

b) **Graduated cup,** with capacity at least 946 cm^3 (1 quart).

c) **Stopwatch**.

d) **Thermometer**, with a range of 0 °C to 105 °C (32 °F to 220 °F).

6.2.2 Procedure

6.2.2.1 Cover the funnel orifice with a finger and pour freshly sampled drilling fluid through the screen into the clean, upright funnel. Fill until fluid reaches the bottom of the screen.

6.2.2.2 Remove finger and start the stopwatch. Measure the time for drilling fluid to fill to the 946 cm^3 (1 quart) mark of the cup.

6.2.2.3 Measure the temperature of the fluid, in degrees Celsius (degrees Fahrenheit).

6.2.2.4 Report the time (6.2.2.2), to the nearest second, with the volume, as the Marsh funnel viscosity. Report the temperature (6.2.2.3) of the fluid to the nearest degree Celsius (degree Fahrenheit).

6.3 Determination of viscosity and/or gel strength using a direct-indicating viscometer

6.3.1 Apparatus

a) **Direct-indicating viscometer,** powered by an electric motor or a hand crank.

Drilling fluid is placed in the annular space between two concentric cylinders. The outer cylinder or rotor sleeve is driven at a constant rotational velocity. The rotation of the rotor sleeve in the fluid produces a torque on the inner cylinder or bob. A torsion spring restrains the movement of the bob, and a dial attached to the bob indicates displacement of the bob. Instrument constants should be adjusted so that plastic viscosity and yield point are obtained by using readings from rotor sleeve speeds of 300 r/min and 600 r/min.

The components shall meet the following specifications.

1) **Rotor sleeve**

Inside diameter	36,83 mm (1,450 in)
Total length:	87,0 mm (3,425 in)
Scribed line:	58,4 mm (2,30 in) above the bottom of sleeve, with two rows of 3,18 mm (0,125 in) holes spaced 120° (2,09 rad) apart, around rotor sleeve just below scribed line.

2) **Bob**, closed, with flat base and tapered top

Diameter:	34,49 mm (1,358 in)
Cylinder length:	38,0 mm (1,496 in)

3) **Torsion spring constant:**

386 dyne-cm/degree deflection

4) **Rotor sleeve speeds**

High speed:	600 r/min
Low speed:	300 r/min

NOTE Other rotor speeds are available in viscometers from various manufacturers.

b) **Stopwatch.**

c) **Thermostatically controlled viscometer cup.**

d) **Thermometer**, with a range of 0 °C to 105 °C (32 °F to 220 °F).

6.3.2 Procedure

6.3.2.1 Place a sample of the drilling fluid in a thermostatically controlled viscometer cup. Leave enough empty volume (approximately 100 cm^3) in the cup for displacement of fluid due to the viscometer bob and sleeve. Immerse the rotor sleeve exactly to the scribed line. Measurements in the field should be made with minimum delay from the time of drilling fluid sampling. Testing should be carried out at either (50 ± 1) °C [(120 ± 2) °F] or (65 ± 1) °C [(150 ± 2) °F]. The place of sampling should be stated on the report.

The maximum recommended operating temperature is 90 °C (200 °F). If fluids have to be tested above this temperature, either a solid metal bob, or a hollow metal bob with a completely dry interior should be used.

CAUTION Liquid trapped inside a hollow bob may vaporize when immersed in high-temperature fluid and cause the bob to explode.

6.3.2.2 Heat (or cool) the sample to the selected temperature. Use intermittent or constant shear at 600 r/min to stir the sample while heating (or cooling) to obtain a uniform sample temperature. After the cup temperature reaches the selected temperature, immerse the thermometer into the sample and continue stirring until the sample reaches the selected temperature. Record the temperature of the sample.

6.3.2.3 With the sleeve rotating at 600 r/min, wait for the viscometer dial reading to reach a steady value (the time required is dependent on the drilling fluid characteristics). Record the dial reading R_{600} in pascals for 600 r/min.

6.3.2.4 Reduce the rotor speed to 300 r/min and wait for the dial reading to reach steady value. Record the dial reading R_{300} in pascals for 300 r/min.

6.3.2.5 Stir the drilling fluid sample for 10 s at 600 r/min.

6.3.2.6 Allow drilling fluid sample to stand undisturbed for 10 s. Slowly and steadily turn the hand-wheel in the appropriate direction to produce a positive dial reading. Record the maximum reading as the initial gel strength. For instruments having a 3 r/min speed, the maximum reading attained after starting rotation at 3 r/min is the initial gel strength. Record the initial gel strength (10-second gel) in pounds per 100 square feet.

NOTE To convert the dial reading to pounds per 100 square feet: 1 Pa = 0,48 lb/100 ft^2.

6.3.2.7 Restir the drilling fluid sample at 600 r/min for 10 s and then allow the drilling fluid to stand undisturbed for 10 min. Repeat the measurements as in 6.3.2.6 and report the maximum reading as the 10-minute gel in pascals (pounds per 100 square feet).

NOTE To convert the dial reading to pounds per 100 square feet: 1 Pa = 0,48 lb/100 ft^2.

6.3.3 Calculation

$$\eta_P = R_{600} - R_{300} \quad (6)$$

$$\eta_Y = 0{,}48 \times (R_{300} - \eta_P) \quad (7)$$

$$\eta_A = R_{600}/2 \quad (8)$$

where

η_P is the plastic viscosity, in millipascal seconds;

NOTE Plastic viscosity is commonly known in the industry by the abbreviation PV.

η_Y is the yield point, in pascals;

η_A is the apparent viscosity, in millipascal seconds;

R_{600} is the dial reading at 600 r/min, in pascals (pounds per 100 square feet);

R_{300} is the dial reading at 300 r/min, in pascals (pounds per 100 square feet).

NOTE 1 To convert to CGS units of centipoise, 1 mPa·s = 1 cP.

NOTE 2 When calculating values in USC units, the yield point (in pounds per 100 square feet) is calculated as follows:

$$\eta_Y = R_{300} - \eta_P$$

7 Filtration

7.1 Principle

7.1.1 Measurement of the filtration behaviour and the filter cake characteristics of an oil-based drilling fluid are fundamental to the treatment and control of a drilling fluid, as are the characteristics of the filtrate, such as the oil, water or emulsion content.

7.1.2 Filtration characteristics of an oil-based drilling fluid are affected by the quantity, type and size of solid particles and emulsified water in the drilling fluid, and by properties of the liquid phase. Interactions of these various components can be influenced by temperature and pressure.

7.1.3 Filtration tests are performed at ambient (low) temperature and at high-temperature conditions to provide data for comparison purposes. Two filtration procedures are given: one for testing up to 175 °C (350 °F) and one for testing from 175 °C (350 °F) to 230 °C (450 °F). Use only the filtration equipment and procedure specified for the temperature required.

NOTE No low-temperature filtration test procedure for oil-based drilling fluids is specified herein, but it can be performed much like the water-based drilling fluid test provided in ISO 10414-1.

7.1.4 Either the 175 cm^3, 250 cm^3, or 500 cm^3 unit can be used for testing filtration up to and including 175 °C (350 °F). For testing above 175 °C (350 °F), only the 500 cm^3 unit shall be used. It shall be equipped with a thermocouple to measure the temperature of drilling fluid in the cell, and it shall use a porous filter media.

7.2 High temperature/high pressure test up to 175 °C (350 °F)

7.2.1 Apparatus

a) **High-temperature/high-pressure filter press**, consisting of:

1) **filter cell**, to contain working pressures up to 9 000 kPa (1 300 psi) at temperature;

2) **pressurized gas source**, such as carbon dioxide or nitrogen, with regulators;

NOTE Nitrogen is preferred.

3) **heating system**, to heat to 175 °C (350 °F);

4) **high-pressure filtrate collection vessel**, maintained at proper back-pressure (see Table 2) to avoid flashing or evaporation of the filtrate;

5) **filter cell**, containing a thermometer well, fitted with a removable end, a filter-media support and with oil-resistant seals.

NOTE Valve stems on each end of the cell can be opened or closed during the test.

CAUTION Not all manufacturers' equipment is capable of achieving the same temperatures and pressures. Rigid adherence to manufacturer's recommendations as to sample volumes, temperatures and pressures is essential. Failure to do so could result in serious injury.

Do not use nitrous oxide cartridges as pressure sources for HT/HP filtration. Under temperature and pressure, nitrous oxide can detonate in the presence of grease, oil or carbonaceous materials. Nitrous oxide cartridges shall be used only for Garrett gas train carbonate analysis (see annex I).

Table 2 — Recommended minimum back-pressure

Test temperature		Vapour pressure		Minimum back-pressure	
°C	(°F)	kPa	(psi)	kPa	(psi)
100	212	101	14,7	690	100
120	250	207	30	690	100
150	300	462	67	690	100
Limit of "normal" field testing					
175	350	932	135	1 104	160
200	400	1 704	247	1 898	275
230	450	2 912	422	3 105	450

b) **Filter medium**[1], including Whatman No. 50 or S&S 576, or equivalent filter paper, for temperatures to 200 °C (400 °F).

c) **Mechanical or electronic timer**, with at least a 30 min interval.

d) **Thermometer**, with a range up to 260 °C (500 °F), and with a 12,5 cm (5 in) or longer stem.

e) **Long, slender graduated cylinder** (TC), with a capacity of 10 cm^3 or 20 cm^3.

f) **Graduated cylinder**, optional, (TC), with a capacity of 25 cm^3.

g) **Field mixer**, cup type, to operate at 10 r/min, 1 000 r/min and 15 000 r/min

h) **Ruler**, measured in millimetres, to measure filter cake thickness.

7.2.2 Procedure for temperatures up to 175 °C (350 °F)

7.2.2.1 Place the thermometer in the well of the heating jacket. Preheat the jacket to approximately 6 °C (10 °F) above the desired test temperature. Adjust the thermostat to the desired test temperature.

If the filtration unit is equipped with a thermocouple to measure drilling fluid temperature inside the cell (test temperature), then that temperature should be monitored and maintained during the filtration test. Results may differ from this standard procedure, which uses the cell wall temperature as the test temperature. Note if the thermocouple method was used.

7.2.2.2 Stir the drilling fluid sample for 5 min using the field mixer. Pour the fluid sample into the filter cell, leaving at least 2,5 cm (1 in) space in the cell to allow for fluid expansion. Install the filter paper in the cell.

7.2.2.3 Complete the assembly of the filter cell, with both top and bottom valves closed, and place it in the heating jacket. Transfer the thermometer from the heating jacket into the well of the filter cell.

7.2.2.4 Connect the high-pressure filtrate collection vessel onto the lower valve stem and lock it in place. Be sure the collection vessel is completely free of water or oil.

7.2.2.5 Connect the regulated pressure source to the upper valve. Connect a similar regulated pressure source to the filtrate collection vessel, and lock these connections in place.

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[1] Whatman No. 50 and S&S 576 are examples of suitable products available commercially. This information is given for the convenience of users of this Standard and does not constitute an endorsement by API of these products.

7.2.2.6 Keeping the two valve stems closed, adjust the pressure on the upper pressure regulator to 690 kPa (100 psi) higher than the minimum back-pressure value, as shown in Table 2. Set the lower regulator to the minimum back-pressure value, as shown in Table 2, for the test temperature. Maintain this pressure until the test temperature is reached.

NOTE If the time required to reach test temperature exceeds 1 h, the heater may be defective and the validity of the test is questionable.

7.2.2.7 When the sample reaches the selected test temperature, open the lower valve stem and immediately increase the pressure on the upper regulator to 3 450 kPa (500 psi) higher than the back-pressure. This will start the filtration process. Start the timer. Maintain the test temperature to within ± 3 °C (± 5 °F) during the test. If the back-pressure rises above the selected back-pressure during the test, cautiously draw off and collect a portion of the filtrate to reduce the back-pressure.

7.2.2.8 Collect the filtrate in the long, slender graduated cylinder (or optional graduated cylinder). Read the volume of the 30-min total (water plus oil) filtrate. Also read volumes of solid and aqueous phases, if present.

NOTE The long, slender glass cylinder allows more accurate detection and measurements of volumes of oil, water and solids in the filtrate. Heating of the cylinder near an emulsion interface can improve separation of water, solids and oil in the filtrate.

7.2.2.9 Immediately after collecting the 30-min filtrate, close the upper and lower valve stems to contain the pressure. Following the manufacturer's detailed instructions, bleed pressure off the regulators and hoses, then disconnect the pressurization system. Remove the cell from the heating jacket and allow cell to cool to below 50 °C (125 °F). Keep the cell upright during cooling, depressurization and disassembly.

CAUTION Pressure in the filter cell can be dangerously high, even after the cell is cooled. Opening cell before pressure is released can result in injury.

7.2.2.10 Bleed pressure from the filter cell by slowly opening the upper valve stem. Avoid spraying drilling fluid as gas exits the stem. Ensure that pressure is fully released before dislodging the cap. Carefully disassemble the cell.

7.2.2.11 Pour the liquid from the cell.

7.2.2.12 Remove the filter cake on the filter paper. Measure the filter cake thickness, at its centre, to the nearest millimetre.

7.2.2.13 Settling of solids onto the filter cake may have occurred during the test. Observe indications of this, such as an abnormally thick cake or coarse texture. Record these cake characteristics. To minimize settling, the times for heat-up and cool-down should be minimized and the cake should be recovered and examined promptly.

7.2.3 Calculation

7.2.3.1 The filtrate volume should be corrected to a filter area of 4 580 mm^2 (7,1 in^2). HT/HP filter cells usually have half the standard filter area or 2 258 mm^2 (3,5 in^2), thus double the observed volume before reporting.

7.2.3.2 Report the cake thickness to the nearest millimetre (32^{nd} inch).